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Report

An estimated map of NO_2 Concentration in the Midlands Region

A report produced for Environment Agency

John R Stedman, Tony Bush, Keith J Vincent and Glenn W Campbell

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AEA Technology

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AEA Technology plc
National Environmental Technology Centre
E5 Culham
ABINGDON
OX14 3DB
Telephone 01235 463034
Facsimile 01235 463178

Report Manager	Name	Glenn Campbell
Approved by	Name	Geoff Dollard
	Signature	GDollard
	Date	12/8/96

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1. Introduction

This report describes the preparation of an estimated map of annual mean background nitrogen dioxide concentrations in the Environment Agency Midlands Region for use in the "First Estimate Workbook".

The networks from which NO_2 data are available are described. The methods that have been used to calculate a UK-wide map of background NO_2 concentrations are briefly discussed. The UK Nitrogen Dioxide Survey (Stevenson and Bush, 1995 and 1996) provides the most appropriate source of data for use in maps specifically for the Midlands Region. The UK-wide map was used select a subset of measurement sites in the Midlands Region with known comparability of data produced by different laboratories performing analyses this survey. The relationships between these measured concentrations and the surrogate statistics required for calculation of a map are described.

The Midlands map calculated using these relationships is presented in a format appropriate for inclusion in a workbook along with approximate factors that can be used to derive statistics such as estimates of kerbside concentrations and 98th percentiles from this annual mean background map.

2. Nitrogen Dioxide Monitoring in the UK

2.1. AUTOMATIC URBAN MONITORING NETWORK

Urban NO_2 concentrations are currently (July 1996) monitored on an hourly basis at 40 locations in the UK using chemiluminescent monitors. These measurements are made within the Department of the Environment (DoE) Automatic Urban Monitoring Network (AUN). The primary objectives of this network are:

- To provide the public with rapid and reliable information on urban air quality.
- To monitor compliance with EC Directives
- To assist in assessing the effectiveness of current air quality policies, and in developing new policies.

Network functions are split between a Central Management and Co-ordination Unit (CMCU, Stanger Science and Environment) and an independent Quality Assurance and Control unit (QA/QC, AEA Technology). The primary responsibilities of the CMCU are site management and preliminary data scaling, while the QA/QC Unit carries out six monthly intercalibrations of all network sites using primary gas standards and ratifies the final datasets. The AUN therefore provides hourly measurements of NO_2 quality assured to a consistent standard to enable detailed comparisons between measurements in different cities throughout the UK.

The scope and coverage of the AUN has increased significantly in recent years and continues to do so. New Government funded city centre monitoring sites are being added to the network and a large

number of local authority monitoring stations are being affiliated to the network; this affiliation includes incorporation of the sites into the quality assurance procedures.

More details of the monitoring methods and site locations can be found in the series of reports summarising the measurements from the DoE national air pollution monitoring networks. (Bower et al, 1995)

2.2. UK NITROGEN DIOXIDE SURVEY

The UK Nitrogen Dioxide Diffusion Tube Survey was established in 1993 and operates throughout the UK in a co-operative programme between the Department of Environment and local authorities. Monitoring takes place within 309 authorities and at approximately 1190 sites nation-wide. (Stevenson and Bush, 1995 and 1996).

The primary aims of the survey are:

- to identify areas of the UK which may require additional monitoring to ensure compliance with the EC Directive on NO_2 concentrations
- to determine trends in NO_2 concentrations throughout the UK from a long running survey with a consistent siting and operational methodology

The survey complements the Automatic Urban Network (AUN), which provides real time measurements of a range of pollutants with detailed information on the spatial distribution of average NO_2 concentrations throughout the UK.

Sampling is performed using passive diffusion tube samplers at four urban locations within each local authority:

- "Kerbside": 1-5m from the kerb of a busy road
- "Intermediate": 20-30m from the same or an equivalent road and
- "Urban Background": >50m from any busy road and typically in residential areas (two sites)

The sampler used in the UK Nitrogen Dioxide Diffusion Tube Survey is based on the work of Palmes *et al* (1976) and Atkins *et al* (1986). Exposure periods are nominally set at one month, producing monthly average NO_2 concentrations.

Standardisation within the network has been ensured by promulgating standard sampler location and handling procedures. Analytical quality control was achieved through a single annual side-by-side comparison at one site. However, as the number of analytical laboratories taking part in the survey (approximately 40) is much larger than originally envisaged, the analytical quality control system has undergone significant evolution recently and is now able to track the analytical performance of laboratories on a month by month basis. The intention here is to identify periods in which analyses from a laboratory have been insufficiently accurate and enable appropriate actions to be taken so that the UK NO_2 Survey dataset is not compromised.

As the data used for mapping were collected before the improved QA/QC system was in place, an initial data screening exercise was carried out. A national map for urban background nitrogen dioxide concentration was prepared using automatic urban monitoring data and the technique described in Section 4. The annual mean concentrations measured by diffusion tube were compared to the expected value from the map derived from automatic monitoring data.

Regression analysis of the mapped NO_2 concentrations versus measured annual average concentrations for individual laboratories was used to identify those which deviated substantially from the 1:1 best fit line. Laboratories producing a regression analysis deviating ≥20% from the 1:1 line were subsequently identified and eliminated from the dataset used for production of the estimated annual average NO_2 concentration map for the Midlands.

2.3. RURAL NITROGEN DIOXIDE MEASUREMENTS

Nitrogen dioxide concentrations are also monitored using diffusion tubes at the 32 rural sites of the UK Acid Deposition monitoring network. Details of this network including the location of the sites can be found in Vincent et al (1995).

3. Calculating a national map of nitrogen dioxide concentrations from available monitoring data

UK-wide maps of annual mean rural NO_2 concentration can be calculated by interpolation from the measurements made at Acid Deposition Network sites. As emissions from the immediate areas (<1km) around each of these rural sites are relatively small, such a map has relatively small spatial gradients in concentration representative of the concentrations expected in locations away from the immediate influence of emissions sources.

In order to map NO_2 concentrations where there are elevated concentrations due to the influence of urban sources (e.g. in urban areas or near major roads), a modelling approach is used. The mean concentration within an area of dispersed emission, such as an urban area, can be estimated using a simple box model. The mean concentration is dependent on the emissions density, the wind speed and the height through which the emissions disperse. The mean concentration, c, in a grid square of length d is:

$$c = \frac{q}{dhu}$$

Where q is the emission rate from a grid square, u the wind speed and h is a height scale factor to represent vertical dispersion.

The height scale factor is dependent on wind speed, the size of the grid square and vertical diffusivity and is difficult to predict. We have therefore used an empirical approach in which the factor $\frac{1}{dhu}$ (hereafter termed k_m) is derived empirically from measurements of concentration and emissions estimates.

Emissions estimates themselves are subject to uncertainties and are currently available from the National Atmospheric Emissions Inventory at a 10 km x 10 km grid resolution. Background NO_2

been estimated on an individual road link basis using standard National Atmospheric Emissions Inventory methods and Department of Transport traffic flow data. Other urban emissions have been modelled using satellite land cover data and have been assumed to be proportional to the percentage of urban and suburban land cover in each grid square.

A regression analysis of the relationship between automatic measurements of NO_2 (actually the difference between the measurement at the urban site and the interpolated rural value) and these surrogate statistics can be used to estimate mapping factors, k_m, for major roads and other urban emissions. The final map is then simply derived from the sum of the interpolated rural map and the local contribution. Such a map has been calculated at a 5 km x 5 km grid square resolution for 1994.

The applicability of this map is determined by the representativeness of the sites used in the regression analysis. Most of the AUN sites used in this analysis are best described as urban centre or urban background locations and are representative of urban areas away from the immediate vicinity of major roads, i.e. urban background.

The contribution to ambient NO_2 concentrations from local industrial sources has not been included in this map since the locations of such sources cannot be determined from the surrogate statistics used.

4. Map of background nitrogen dioxide concentrations for the Midlands Region

4.1. UK NITROGEN DIOXIDE SURVEY DATA FOR THE MIDLANDS REGION

The national mapping procedure does not take account of any variation in the k_m factors for different regions of the UK. It therefore ignores variation in meteorology over the UK and regional variation in emissions characteristics (e.g. the age of the vehicle fleet). As the First Estimate Workbook is designed to be specific to an Environment Agency Region, a map for the Midlands Region has been prepared using data specific to the region.

There are insufficient automatic monitoring sites to use the data in a regression analysis and data from UK Nitrogen Dioxide Survey have therefore been used. Figure 1 shows the location of the urban background monitoring locations selected from the UK dataset after application of the initial screening procedure outlined in Section 2.2.

4.2. THE MAP

The following relationship was found between the measured annual mean NO_2 concentration at this reduced set of 46 background sites and the surrogate statistics:

$$NO_2 \text{ (ppb)} = \mathbf{rural\_NO_2} + 0.173*\mathbf{lcov} + 0.085*\mathbf{noxem}$$

where:

$$NO_2 \text{ (ppb)} = \textbf{rural\_NO}_2 + 0.173*\textbf{lcov} + 0.085*\textbf{noxem}$$

where:

rural_NO_2 is the concentration of NO_2 from the map interpolated from rural NO_2 measurements;

lcov is the mean percentage of (urban + suburban) land cover for a 5 km x 5 km grid square centred at the monitoring location;

noxem is the total annual NO_x emission from major road vehicle sources (in tonnes per square km) within the 2 km x 2 km grid square surrounding the monitoring site.

Note that different grid sizes are used for land cover and major roads emissions. The choice of grid size was derived from a correlation analysis of the measured concentrations, land cover and major roads data for differing grid sizes between 1 km x1 km and 20 km x 20 km using the national automatic monitoring dataset. The grid size giving the largest correlation was used in each case.

The above relationship has been used to calculate estimates of background NO_2 concentration for each 1 km x 1 km grid square in the Midlands Region (the map is at 1 km x 1 km resolution but is derived from 2 km x2 km and 5 km x 5 km emissions estimates centred at the 1 km x 1 km grid nodes). Figure 2 shows a comparison between these estimates and the UK Nitrogen Dioxide Survey data from background sites. The map of estimated annual mean background NO_2 concentration presented in Figure 3 was calculated by taking the mean of the 25 1 km x 1 km squares making up each 5 km x 5 km grid square. The values in this map have been rounded up to the nearest 5 ppb for ease of use and to provide some indication of the likely uncertainties in the mapping procedure.

5. Approximate factors for calculating other statistics

5.1. KERBSIDE AND INTERMEDIATE LOCATIONS

The measured ratios of the mean kerbside and mean intermediate NO_2 concentrations to the mean background NO_2 concentration for 1994 in the Midlands Region were:

ratio of kerbside to background: **1.7**
ratio of intermediate to background: **1.2**

These ratios are very similar to those obtained for the whole UK Nitrogen Dioxide Survey 1994 datasets and can be used to estimate kerbside or intermediate NO_2 concentrations in the Midlands Region by multiplying the estimated background NO_2 concentration read from the map presented in Figure 3 by the appropriate factor.

very similar to the relationship obtained if all the years of monitoring since 1976 are included on such a plot.

6. Acknowledgements

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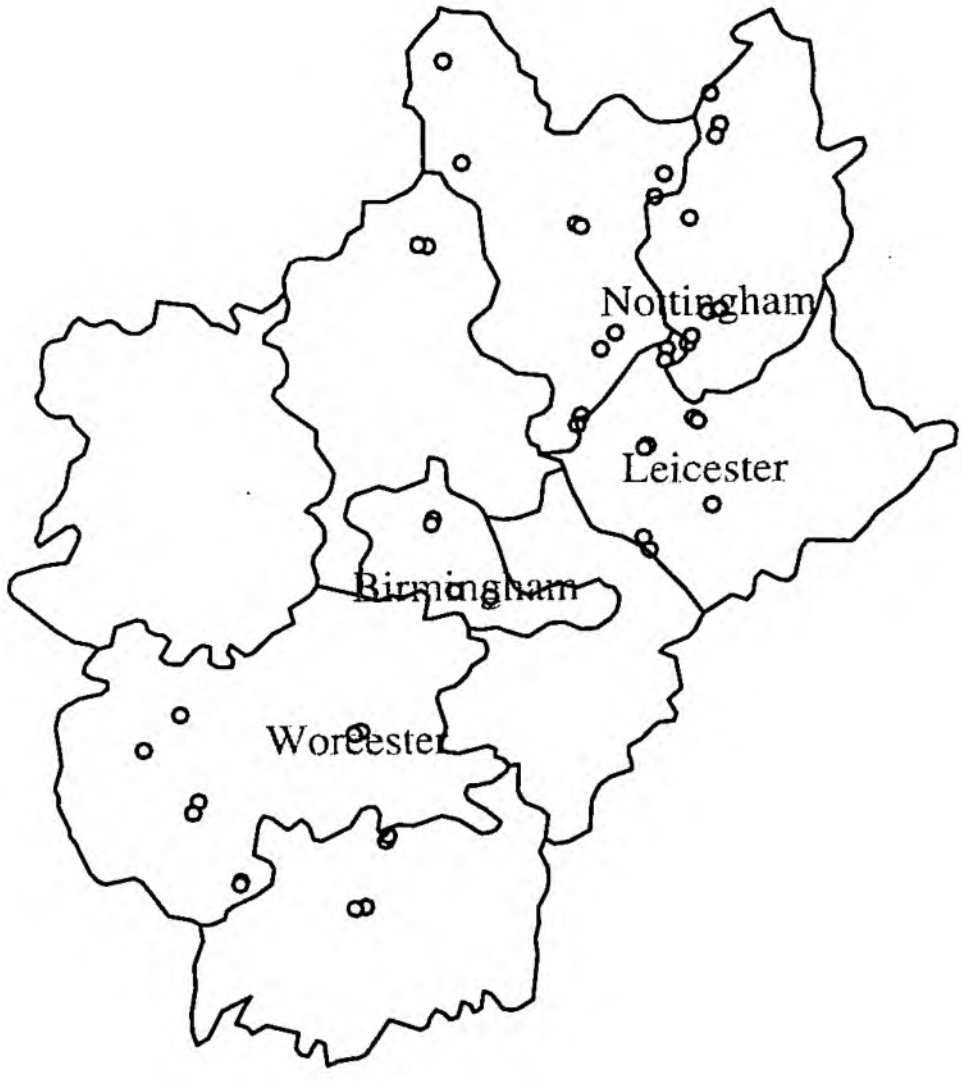

Figure 1 Location of Diffusion Tube Monitoring Sites in the Midlands Used in Mapping

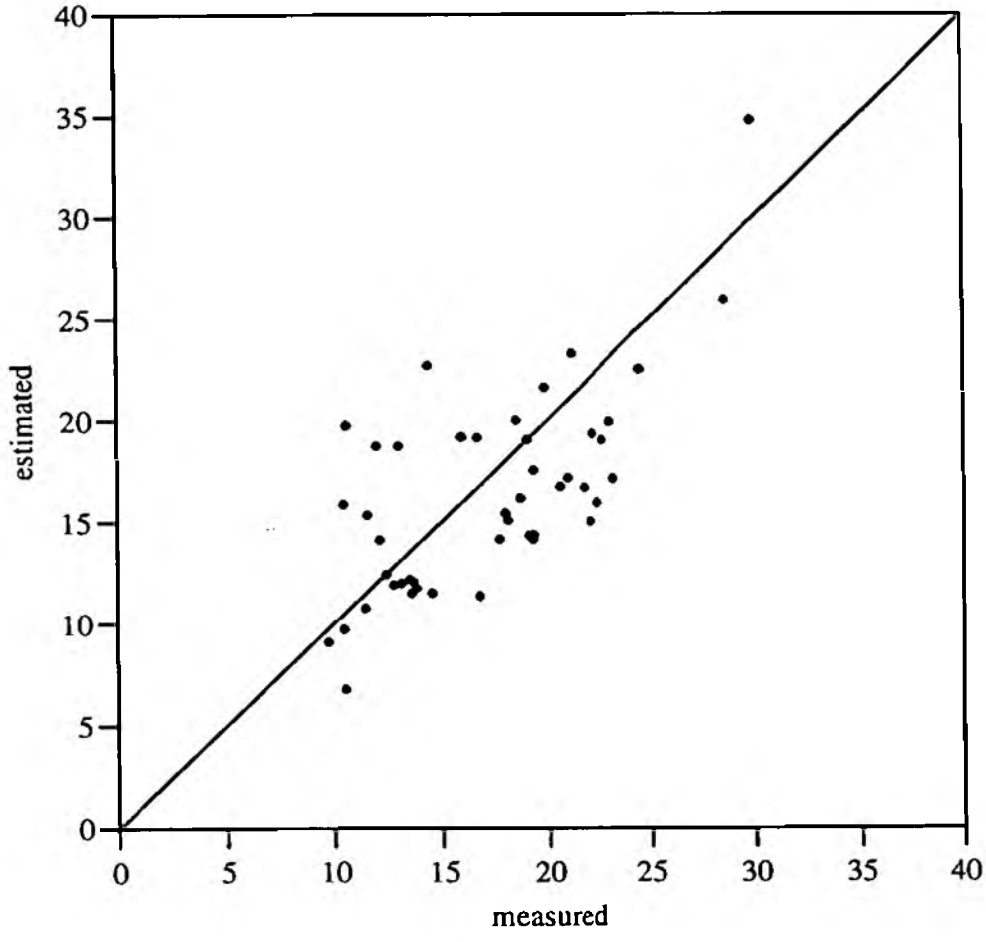

Figure 2. Comparison of Measured (from the UK NO_2 Survey) and Estimated (from the map) Values of Annual Mean Nitrogen Dioxide Concentration in 1994 (ppb)

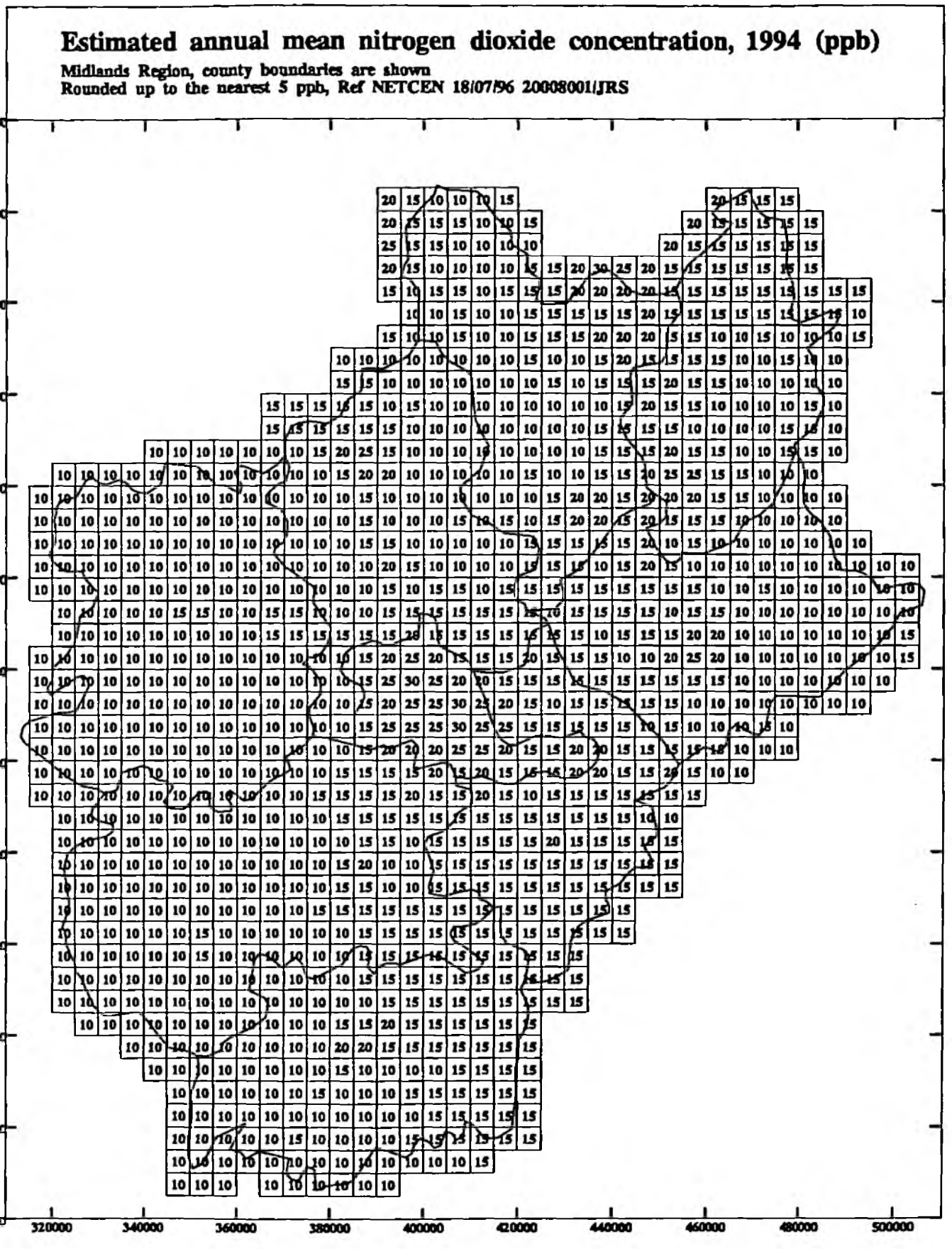

Figure 3. A Map of Estimated Annual Mean Nitrogen Dioxide Concentration for Background Locations in The Midlands.

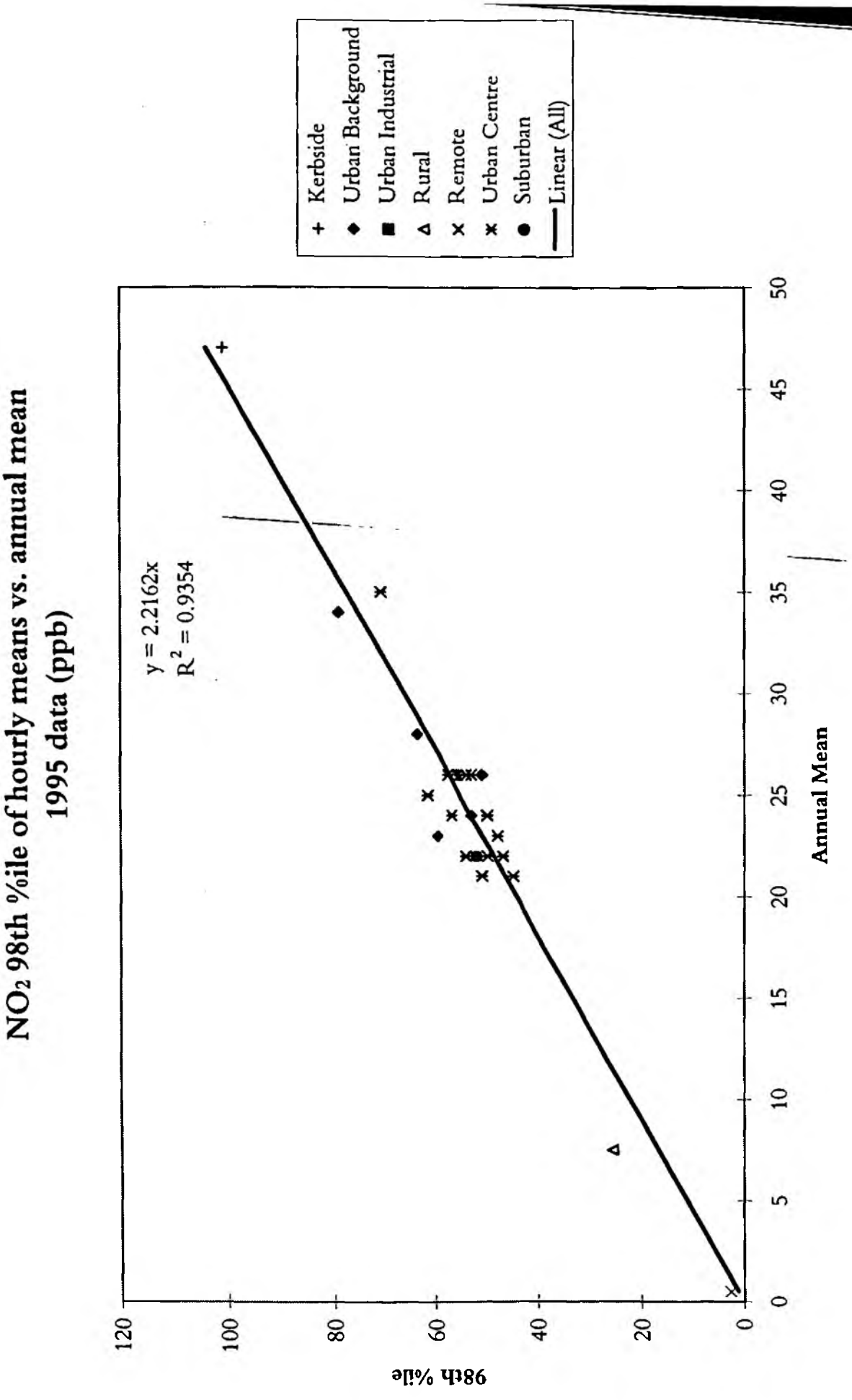

Figure 4. Comparison of 98th Percentile Hourly Mean Nitrogen Dioxide Concentration and the Annual Mean